10-26-00

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EXPRESS MAIL RECEIPT NO.: EK281428778US
DEPOSITED ON OCTOBER 24, 2000

PATENT
Dkt. 23060

Preliminary Classification:
Proposed Class:
Subclass:

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Box Patent Application
Commissioner for Patents
Washington, D.C. 20231

NEW APPLICATION TRANSMITTAL

Transmitted herewith for filing is the patent application of

Inventor(s): **Jack A. Mobley; Jason D. Gregg; Kenny T. Coker; Leonard D. Doss**

For (title): **IMPROVING PERFORMANCE IN A DISC DRIVE USING HEAD-TO-HEAD OFFSETS IN ACCESS COMMAND SCHEDULING**

1. Type of Application

This transmittal is for an original (nonprovisional) application.

2. Papers Enclosed

A. Required for filing date under 37 C.F.R. 1.53(b) (Regular) or 37 C.F.R. 1.153 (Design) Application

17 Pages of Specification
6 Pages of Claims
6 Sheets of Drawings--Formal

B. Other Papers Enclosed

3 Pages of Declaration
2 Pages of Power of Attorney with 3 sheets of executed Assignment
1 Page of Abstract

3. **Additional Papers Enclosed**

3 Pages of Information Disclosure Statement (37 C.F.R. 1.98), including Form PTO-1449 (PTO/SB/08A and 08B) with 9 references of cited art

Acknowledgment Postcard

4. **Declaration or Oath**

Enclosed and executed by inventors: Jack A. Mobley, Jason D. Gregg, Kenny T. Coker and Leonard D. Doss

5. **Inventorship Statement**

The inventorship for all the claims in this application is the same.

6. **Language**

English

7. **Assignment**

An assignment of the invention to SEAGATE TECHNOLOGY LLC is attached. A separate FORM PTO 1595 is also attached.

8. **Fee Calculation (37 C.F.R. Section 1.16)**

Regular Application

CLAIMS AS FILED

Claims	Number Filed	Basic Fee Allowance	Number Extra		Rate	Basic Fee 37 CFR 1.16(a) $710.00
Total Claims (37 CFR 1.16(c))	14	- 20 =	0	x	$18.00	$0.00
Independent Claims (37 CFR 1.16(b))	3	- 3 =	0	x	$80.00	$0.00
Multiple Dependent Claim(s), if any (37 CFR 1.16(d))				+	$260.00	$0.00

Filing Fee Calculation	$710.00

9. Fee Payment Being Made at This Time

Enclosed

Filing Fee	$710.00
Recording assignment ($40; 37 C.F.R. Section 1.21(h))	$ 40.00
Total Fees Enclosed	$750.00

10. Method of Payment of Fees

Two checks in the amounts of $710.00 and $40.00 are attached.

11. Authorization to Charge Additional Fees

The Commissioner is hereby authorized to charge the following additional fees by this paper and during the entire pendency of this application to Account No. 13-0110.

37 C.F.R. Section 1.16(a), (f) or (g) (filing fees)

37 C.F.R. Section 1.16(b), (c) or (d) (presentation of extra claims)

37 C.F.R. Section 1.17(a)(1)-(5) (extension fees pursuant to SECTION 1.136(a))

37 C.F.R. Section 1.17 (application processing fees)

12. Instructions as to Overpayment

Refund.

ADDED PAGES FOR NEW APPLICATION TRANSMITTAL WHERE BENEFIT OF PRIOR U.S. APPLICATION CLAIMED

13. Relate Back

A. 35 U.S.C. Section 119(e)

This application claims the benefit of U.S. Provisional Application No.:

APPLICATION NO.	**FILING DATE**
60/183,102	February 17, 2000

14. **Further Inventorship Statement Where Benefit of Prior Application(s) Claimed**

a. This application discloses and claims only subject matter disclosed in the prior application whose particulars are set out above and the inventors in this application are the same.

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PATENT APPLICATION
DOCKET NO. 23060

APPLICATION

Of

JACK A. MOBLEY, JASON D. GREGG,
KENNY T. COKER AND LEONARD D. DOSS

For

UNITED STATES LETTERS PATENT

On

IMPROVING PERFORMANCE IN A DISC DRIVE USING HEAD-TO-HEAD OFFSETS IN ACCESS COMMAND SCHEDULING

Docket: 23060
Sheets of Drawings: 6

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IMPROVING PERFORMANCE IN A DISC DRIVE USING HEAD-TO-HEAD OFFSETS IN ACCESS COMMAND SCHEDULING

Related Applications

This application claims priority to Provisional Application No. 60/183,102 filed February 17, 2000.

Field the Invention

This invention relates generally to the field of magnetic data storage devices, and more particularly, but not by way of limitation, to improving disc drive operational performance by adaptively adjusting estimated seek times to account for head-to-head offsets to improve the sorting and execution of queued access commands in a command queue of a disc drive.

Background

Disc drives are used as primary data storage devices in modern computer systems. A typical disc drive includes one or more axially aligned discs that are rotated at a high speed by a spindle motor. Each disc surface has a plurality of concentric tracks defined by servo data written to the discs during manufacturing. Each track includes a plurality of user data fields, or sectors, to which user data are written and from which user data are subsequently read by the heads. All of the tracks on each of the disc surfaces at a given radius collectively make up a cylinder.

A corresponding array of read/write transducing heads are supported adjacent the discs and used to transfer data between the discs and a host computer in which the disc drive is mounted. It is desirable to vertically align the heads such that each head is adjacent the same cylinder at all times; nevertheless, some positional offset will typically exists between each of the heads. The heads are supported by a rotary actuator assembly which controllably moves the heads across

the disc surfaces in response to a servo control system. Individual sectors are accessed for read and write operations in response to commands from the host computer.

A disc drive is further provided with host interface electronics that conform to a selected industry standard protocol to facilitate communication and data transfer between the disc drive and the host computer. Such protocols can allow the host computer to send multiple access commands to the drive at a time, and the commands are stored in a memory location (also referred to as a "command queue") pending execution by the drive. For example, disc drives using the Small Computer System Interface (SCSI) protocol can typically store up to 64 pending commands in the command queue.

When multiple commands are available for execution, the disc drive is typically configured to employ a sorting strategy to execute the commands in an order that minimizes the time necessary to access the associated sectors. A particularly useful command queue sorting strategy is disclosed by U.S. Patent No. 5,570,332 issued to Heath et al., assigned to the assignee of the present application.

In order for the host interface electronics to determine an optimal order of execution of the pending commands, a valid estimate of time to access each of the associated sectors is needed. As will be recognized, the total access time for a drive to access a desired sector on a selected disc surface includes a (relatively short) overhead time to process the access command, a seek time during which a seek operation is performed to move the actuator from an initial cylinder to a destination cylinder so that the appropriate head is settled onto the destination track containing the desired sector, and a rotational latency time during which the drive waits for the disc to rotate the desired sector around to a position under the selected head.

To enable accurate sorting of pending access commands, disc drives typically maintain a seek profile table of values indicative of average seek time for each seek length. It is common to maintain this table as a running average so that the table is updated as each successive seek is executed. A default seek profile table, which may be generated and permanently saved to the drive in a

manufacturing process, may be loaded during power-on initialization and before normal operation is entered.

For reference, a typical overhead time is usually on the order of a few microseconds, μsec (10^{-6} seconds). A typical seek time will vary widely depending upon the length of the seek (i.e., whether the head is only moved a few tracks or across substantially the entire radius of the disc), but will typically range from 1-2 milliseconds, msec (10^{-3} seconds) for a short seek and up to about 10-12 msec for a long seek. Latency is a function of both rotational speed of the discs as well as the angular position of the desired sector with respect to the head. For a spindle motor rotational speed of about 10,000 revolutions per minute (rpm), one disc revolution will take about 6 msec; hence, latency can vary from almost no time at all to a full 6 msec. Of course, using different rotational speeds results in different full latency times. It will be noted that, except for the case of relatively long seeks, latency is generally the largest contributing factor to total access time.

The evaluation of a particular access command for execution at any given time must take into account not only how far away the destination track is located, but also the angular position of the destination sector with respect to the head. If the disc drive cannot reach the destination track before the destination sector "passes" the head, then an entire revolution of the disc (a full rotational latency period) will have to occur before the head can access the desired sector. This is sometimes referred to as a "burned" revolution, and is highly undesirable since burned revolutions reduce the overall data transfer rate sustained by the disc drive.

A disc drive is typically in a track-following mode of operation when evaluating the access commands in the command queue, so that a selected one of the heads is actively maintained over a corresponding track on the associated disc surface (usually the last accessed track by the disc drive). The pending access commands in the command queue, however, may be associated with destination sectors on disc surfaces other than the one over which the presently active head is located. Thus, when evaluating each of the pending access commands in the command queue, the disc drive typically determines the distance to the target track by determining the number of tracks between the track being followed by the

presently active head and the destination cylinder containing the target track, which assumes that all of the heads are nominally aligned.

As track densities continue to increase, the amount of inter-head radial spacing becomes increasingly significant and detracts from the ability of the drive to accurately determine the actual distance to the target track. For example, if the destination cylinder is 30 tracks away from the presently selected head, and the target head is offset from the presently selected head a distance of two tracks in the opposite direction, then the actual seek distance required to place the target head over the target track is 32 tracks, not 30. However, the controller will schedule the access command based on a 30 track seek, leaving open the possibility that the target head will not reach the target track within the expected time (and require a burned revolution).

Accordingly, there is a continued need to develop an efficient method whereby head offsets are taken into consideration when performing combined seek/head switch operations to provide better estimates of actual seek time when sorting pending access commands.

Summary of the Invention

The present invention provides an apparatus and method for improving disc drive data transfer rate performance.

In accordance with preferred embodiments, a disc drive includes a plurality of recording surfaces on which a plurality of concentric data tracks are respectively defined. A servo circuit performs seeks to move a plurality of heads from an initial track to a destination track. A control processor schedules a plurality of pending access commands stored in a command queue.

For each pending access command that requires a head switch from a presently active head to another target head, an estimated seek length is calculated as the radial distance between the destination cylinder in which the destination track is located and the initial cylinder over which the presently active head is located. A positional offset between each of the plurality of heads is measured and applied to the estimated seek length to calculate a corrected seek distance

indicative of the actual distance between the target head and the destination track. A corrected seek time is calculated from a seek profile table in relation to the corrected seek distance. The corrected seek time is used by the control processor to schedule the access commands stored in the command queue.

These and other features and advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. 1 is a top plan view of a disc drive constructed in accordance with preferred embodiments of the present invention.

FIG. 2 illustrates the manner in which servo data are stored on the discs of the disc drive of FIG. 1.

FIG. 3 shows the relative relationship between servo fields and user data fields (sectors) on a selected track on the disc of FIG. 2.

FIG. 4 is a generalized functional block diagram of the disc drive of FIG. 1.

FIG. 5 illustrates the separate elements that comprise a total access time associated with accessing a selected sector on the disc of FIG. 2.

FIG. 6 illustrates seek time variation for a population of seeks of a given seek length distance, in which the seek time variation is reasonably well controlled.

FIG. 7 illustrates seek time variation for another population of seeks of a different seek length distance, in which the seek time variation is less well controlled.

FIG. 8 illustrates the relative position of heads and seek distances for heads exhibiting no positional offset.

FIG. 9 illustrates the relative position of heads and seek distances for heads exhibiting positional offset.

FIG. 10 is a flow chart for a ACCESS COMMAND SCHEDULING routine, illustrative of steps carried out by the control processor of FIG. 4 in accordance with preferred embodiments of the present invention.

Detailed Description

In order to provide a detailed description of various preferred embodiments of the present invention, reference is first made to FIG. 1, which provides a top plan view of a disc drive 100 of the type used to interface with a host computer to magnetically store and retrieve user data. The disc drive 100 includes a base deck 102 to which various components of the disc drive 100 are mounted. A top cover 104 (shown in partial cutaway fashion) cooperates with the base deck 102 to form an internal, sealed environment for the disc drive.

A spindle motor (shown generally at 106) is provided to rotate a plurality of axially-aligned, rigid, magnetic recording discs 108 at a constant speed in rotational direction 109. User data are written to and read from tracks (not designated) on the discs 108 through the use of an actuator assembly 110, which rotates about a bearing shaft assembly 112 positioned adjacent the discs 108.

The actuator assembly 110 includes a plurality of rigid actuator arms 114 which extend toward the discs 108. A plurality of flexible suspension assemblies 116 (flexures) are attached to the distal end of the actuator arms 114. A head 118 is mounted at the distal end of each of the flexures 116 and includes a slider assembly (not separately designated) designed to fly in close proximity to the corresponding surface of the associated disc 108. When the disc drive 100 is deactivated, the heads 118 come to rest on texturized landing zones 120 and the actuator assembly 110 is secured using a magnetic latch 122.

The actuator assembly 110 is rotated using a voice coil motor (VCM) 124, which includes an actuator coil 126. A flex circuit assembly 128 provides electrical communication paths between the actuator assembly 110 and a disc drive printed circuit board assembly (PCBA) mounted to the underside of the base deck 102. The flex circuit assembly 128 includes a preamplifier/driver circuit 129 ("preamp") which applies currents to the heads 118 to read and write data.

FIGS. 2 and 3 generally illustrate the manner in which servo data are stored on the disc surfaces, the servo data enabling servo control circuitry on the PCBA to detect head position and velocity in order to position the actuator in a desired relation to the discs. The servo data are written using a servo track write (STW)

process during disc drive manufacturing and are arranged in a plurality of radially extending servo wedges 130. Each wedge 130 comprises a plurality of adjacent servo fields 132 which are radially aligned to define each of the tracks on the disc surface (a portion of one such track is represented at 133 in FIG. 3).

User data fields 134 (also "data sectors" or "sectors") are defined between adjacent servo fields 132 during a disc drive formatting operation. It will be recognized that the data sectors 134 are typically much longer than the servo fields 132 in order to maximize data capacity, so that the aspect ratios and relative lengths of the fields in FIG. 3 are not represented to scale.

FIG. 4 provides a functional block diagram of relevant portions of the control circuitry supported on the disc drive PCBA, including a read/write channel 136, a servo control circuit 138 with programmable digital signal processor (DSP) 140, top level control processor 142 with associated memory 144, and interface control electronics 146.

The read/write channel 136 operates as a communication channel to encode input data to be written to the discs 108 and to decode amplified readback signals from the preamp 129 to reconstruct data retrieved from the discs 108.

The servo control circuit 138 operates to demodulate head position and velocity from the servo data from the servo fields 132 (FIG. 3) and applies currents to the coil 126 to rotate the actuator assembly 110 accordingly. The servo control circuit 138 further provides drive currents to the spindle motor 106 to rotate the discs 108 at operational speed during drive operation. For purposes of the present discussion, it will be contemplated that the servo control circuit 138 rotates the spindle motor 106 at a nominal operational speed of 10,000 revolutions per minute (rpm).

The control processor 142 provides top level control for the disc drive 100 in accordance with programming steps stored in processor memory 144 and host commands provided by a host computer (not shown).

The interface electronics 146 includes a host interface (I/F) circuit 148 which controls the transfer of data and commands between the disc drive 100 and the host. A buffer 150 (with cache memory 152) temporarily stores data that are

being transferred between the host and the discs 108. More particularly, during a write operation the host loads the buffer 150 with data to be written to the discs 108, and the loaded data are sequentially passed to the read/write channel 136 for processing. During a read operation, the read/write channel 136 sequentially loads the buffer 150 with data retrieved from the discs 108 for subsequent transfer to the host. A buffer control circuit 154 controls the flow of data in and out of the buffer 150.

An error correction circuit (ECC) 156 applies on-the-fly error detection and correction algorithms to the retrieved data to correct detected errors in the retrieved data in the buffer 150. A disc control circuit 158 sequences the read and write operations by the read/write channel 136. A processor interface (I/F) 160 provides a communication path with the control processor 142.

For purposes of the present discussion, it will be contemplated that the interface electronics 146 uses the Small Computer System Interface (SCSI) host interface protocol, although such is not limiting to the scope of the invention as claimed below. Hence, the host I/F 148 includes a memory location, CR (command queue) 162 that can concurrently store up to 64 pending access commands from the host. One type of access command is a write command from the host to write a block of data loaded into the buffer 150 by the host to a selected sector 134 (FIG. 3) on a selected disc surface; another type of access command is a read command from the host to retrieve the contents of a selected sector 134 (FIG. 3) on a selected disc surface to the buffer 150 for subsequent transfer to the host. It will be noted that the host employs logical block addresses (LBAs) to identify the desired sectors 134, and the control processor 142 converts each LBA to a physical block address (PBA) to identify the cylinder, disc surface and angular location of the desired sector.

When multiple access commands are pending in the command queue 162, the control processor 142 applies a sorting strategy designed to maximize data transfer rate performance. This strategy includes the evaluation of the total access time required to access each of the associated data sectors 134 referenced by the pending commands. As illustrated by FIG. 5, the total access time (also referred to

as "phase") includes a relatively short overhead period (block 164) to process the instructions and prepare the disc drive for execution, a seek time (block 166) necessary to bring the associated head 118 over the track 133 containing the desired sector 134, and then latency time (block 168) necessary to allow the desired sector 134 to rotate around and reach the head 118.

Each seek operation of block 166 generally includes steps of applying current to the coil 126 to initially accelerate the head 118 in the desired direction, subsequently applying current to the coil 126 in the opposite direction to decelerate the head 118 to a position adjacent the destination track, and then applying additional control inputs as necessary to settle the head 118 onto the destination track within acceptable limits (as a percentage of off-track width away from the center of the track).

Relatively longer seeks are typically carried out using a velocity controlled approach, in which current is applied to cause the head 118 to follow a predetermined velocity profile to move from the initial track to the destination track. Shorter seeks can be carried out using a model reference seek, wherein a sinusoidal reference current profile is applied, such as a 1-cos curve, to provide a reference velocity which the head 118 follows to the destination track. Both velocity controlled seeks and model reference seeks are known in the art, and are respectively discussed in U.S. Patent No. 5,475,545 issued to Hampshire et al. and U.S. Patent No. 6,031,684 issued to Gregg et al.

As previously mentioned, when multiple access commands are pending in the command queue 162 of FIG. 4, a sorting strategy is employed to carry out the pending commands in an order that maximizes data transfer rate. Irrespective of the particular sorting strategy employed, it is necessary for the control processor 142 to have an accurate indication of the expected seek time (block 166) for each seek length necessary to reach the sectors 134 associated with the command queue. If the actual time necessary to complete the seek is longer than expected, the head may not reach the destination track in time, requiring the drive to burn a full revolution before the desired sector 134 comes around again for access by the head

118. The greater the seek time variation, the more likely that burned revolutions will occur and overall sustained transfer rate will be decreased.

As will be recognized, the amount of seek time variation for a population of seeks of any given length depends on a variety of factors. One such factor is the particular control methodology employed to carry out the seek. Depending upon the configuration of the drive and length of the seek, model reference seeks have been found to provide average seek times of from less than 1 msec to about 3 msec, with upwards of 2 msec of seek time variation for a given seek length. Velocity controlled seeks have been found to provide average seek times of from about 3 msec (for short seeks) to about 12 msec or more (for full stroke seeks), with upwards of about 1 msec of seek time variation for a given seek length.

Another factor that introduces seek time variation is settling performance, which in turn can be influenced by mechanical resonance characteristics of the actuator assembly 110, as well as the various electrical parameter values (gain, etc.) selected for used during the seek (that is, how well the drive is "tuned" for the particular seek length). As discussed above, a seek is not completed until the head 118 is sufficiently on-track for a sufficient period of time to ensure that the access operation can be carried out successfully. This is sometimes referred to as "on-track qualification."

To achieve on-track qualification, the servo control circuit 138 will typically require that the head 118 read a selected number of successive servo fields 132 on the destination track and determine that the head 118 is within the acceptable off-track limits for each of the servo fields. Typical requirements can be the detection of three successive servo fields 132 with the head 118 within ±20% of track center for a read operation, and five successive servo fields 132 with the head 118 within ±15% of track center for a write operation. The more stringent requirements for a write operation are typically employed due to the fact that the magnetic characteristics of the discs 108 are altered during a write operation, and it is important to not inadvertently overwrite existing data on an adjacent track. It follows that drives that have different on-track qualification requirements for read and write operations can have different average seek times for the same length

seek, depending upon whether the access operation is a read or write operation. In such case, the drives can either maintain separate read and write seek tables, or elect to use the values for the longer seek type (which will typically be the write seek). It will be noted that the present invention can be readily configured to use different seek times based on access operation type.

Because of this qualification requirement, poor settling performance can introduce significant amounts of seek time variation, as contrasted by FIGS. 6 and 7. A population of seeks for a given seek length with reasonably well behaved settling characteristics will typically provide a well defined accumulated population curve, such as represented at 170 in FIG. 6. The population curve 170, plotted against an x-axis 172 indicative of total seek time and a y-axis 174 indicative of number of seeks, represents a statistically significant number of seeks of identical length. It will be noted that the curve 170 is unimodal and skewed to the left (asymmetric).

By contrast, FIG. 7 illustrates a population of seeks (curve 176) for a given seek length with relatively poor settling characteristics. The response is multimodal, indicative of excessive oscillation of the head 118 upon reaching the destination track. The subsequent modes, or peaks, in the curve 176 generally arise due to the additional number of servo fields 132 necessary for qualification. That is, depending upon the extent of the oscillation of the head 118 when the destination track is reached, additional servo fields 132 may have to be read before servo qualification is obtained, undesirably extending the overall seek time.

Turning now to FIGS. 8 and 9, provided therein is a graphical representation of the effects of head offset on a seek operation to move and switch from a presently active head 178 adjacent an initial cylinder 180 to a different, target head 182 over a destination track in a destination cylinder 184. As shown, the two discs 108 each include two recording surfaces 186, however it will be understood that additional configurations for the disc drive 100 are encompassed by the present invention.

Referring to FIG. 8, at the onset of a seek operation, the servo control circuit 138 calculates the estimated seek length 188 as the radial distance (in

"tracks to go") between the position of the presently active head 178 over the initial cylinder 180 and the destination cylinder 184. The servo control circuit 138 then applies current to the VCM 124 in relation to the estimated seek length 188 to move the presently active head 178 from the initial cylinder 180 to the destination cylinder 184. Upon settling over the destination cylinder 184, the preamp 129 performs a head switch operation to switch to the target head 182 in order to perform the read/write operation.

As shown in FIG. 8, each of the heads 118 are vertically aligned with one another over the initial cylinder 180. As such, at the close of the seek operation, each of the heads 118 will be located adjacent the destination cylinder 184. When switched active, the target head 182 will be properly positioned over the destination cylinder, thus eliminating the need for a second seek to place the target head 182 above the destination cylinder 184.

However, as track densities continue to increase, it becomes less likely that a plurality of heads 118 will be vertically aligned over any given cylinder on the discs 108. With reference to FIG. 9, the heads 118 are shown exhibiting various degrees of radial offset from the presently active head 178 located above the initial cylinder 180.

As described above, the seek operation begins by calculating the estimated seek length 188 based on the radial distance between the initial cylinder 180 over which the presently active head 178 is located and the destination cylinder 184. Due to the radial offset between heads 178 and 182, the actual distance between the target head 182 and the destination cylinder 184, shown by an actual seek length 190, is larger than the estimated seek length 188. When the seek operation is performed in relation to the estimated seek length 188, the target head 182 may "undershoot" the destination cylinder 184 by an amount equivalent to the radial offset exhibited between the presently active head 178 and the target head 182. When switched active, a second seek operation will be required to settle the target head 182 onto the destination cylinder 184, thus increasing the seek and total access times.

In a queued environment, increased emphasis is placed on seek time estimation. As mentioned above, a seek profile table is used to estimate the time associated with each pending access command in the command queue 162. Commonly, these pending access commands are prioritized based on how closely the estimated seek time coincides with the amount of latency expected between read/write operations. In other words, the most time intensive access commands are executed when a larger degree of latency is experienced between read/write operations. Likewise, seek operations requiring smaller total access times are executed when smaller latency times are expected. Ideally, the seek operation would place and qualify the target head 182 over the destination cylinder just before the target data sector 134 passes beneath the target head 182.

Because the average seek times used to sort the command queue are based on seek length, an incorrect estimated seek length will propagate a degree of error into the estimation of seek time. Consequently, the faulty estimation of seek times adversely impacts the operation of the command queue 162 and may result in excessive total access times, due to the need for burned revolutions.

To compensate for head offset when estimating seek times, presently preferred embodiments of the present invention employ a head offset table. The elements of this table are a representation of the offset, in tracks, from one head to another. Preferably, the table is updated every time the servo control circuit 138 is commanded to perform a seek which results in a sequential head switch (a head switch from a head to either of its adjacent heads). The head offset table is preferably stored within the processor memory 144. However, it will be understood that the head offset table may be stored in alternative locations, such as, for example, in memory within the servo control circuit 138. The logical form of with typical values of offsets is presented below in TABLE 1.

HEAD	OFFSET FROM PREVIOUS HEAD IN TABLE (IN TRACKS)
0	-5.50
1	1.25

2	2.5
3	0.95

Table 1 – Head Offset Table

The above table is an example of the formatting preferred for the head offset table for use in a disc drive employing four heads 118. It will be understood that other representations, including greater or lesser numbers of heads, are considered within the scope of the present invention.

To use this table to resolve the offsets from any head, H1, to a second head, H2, the following methodology is used: if H1 is less than H2 then the offsets in the table are summed from H1+1 to H2. If H1 is greater than H2, then the offsets are summed from H1+1 to the last numbered head in the table and added to the summation of the offsets from the first head in the table to H2. Applying this to the values provided in the sample table, the offset exhibited in a switch from head 0 to head 3 is 4.7 tracks; the offset experienced in a switch from head 3 to head 2 is –1.75 tracks.

The initial offset values for the head offset table are preferably determined during operation. The head offset values may be calculated during idle time, after an predetermined elapsed period of time or after a measured operational event, such as, for example, at such time as the disc drive reaches a steady-state operational temperature.

To measure head offset, the disc drive 100 is placed in track following mode on a first head. The disc drive is then switched to a second head for a length of time sufficient to read a cylinder number and a position error signal (PES). While reading the cylinder and PES, the control signal is held constant, that is, no attempt is made to correct the position of the second head. The PES is recorded and stored as the head offset value between the first and second heads. Although the presently preferred method for determining head offsets has been disclosed above, a variety of means for determining head offsets have been disclosed in the prior art and are encompassed within the scope of the present invention. For

example, see United States Patent No. 5,956,201 issued September 21, 1999 to Pham et al. and assigned to the assignee of the present invention.

Referring now to FIG. 10, shown therein is a flow chart for an ACCESS COMMAND SCHEDULING routine 192. It is contemplated that the routine 192 is performed as part of the command queue sorting strategy adopted by the disc drive 100 and used to evaluate each of a number of concurrently pending access commands in the command queue 162 (FIG. 4).

At step 194, the control processor calculates an estimated seek length 188 for a first selected pending access command. The estimated seek length 188 is calculated as the radial distance (in tracks) between the radial position of the currently active head 178 (FIG. 9) over the initial cylinder 180 and the destination cylinder 184. At step 196, the control processor 142 reads the head offset value corresponding to the head offset exhibited between the presently active head 178 and the target head 182 from the head offset table stored in the processor memory 144. At step 198, the control processor 142 applies the head offset value retrieved from the head offset table to the estimated seek length 188. At step 200, the sum of the head offset value and the estimated seek length 188 is rounded to the nearest whole track to produce a corrected seek length 190. It will be noted that if no head switch is necessary (i.e., the presently selected head and the target head are the same head), then head offset is zero and the corrected seek length 190 is the same as the estimated seek length 188.

At step 202, the corrected seek length 190 is used to retrieve an average seek time for the pending access command from the seek profile table. The routine 192 next passes to decision step 204 where the control processor 142 determines if corrected seek times have been determined for all pending seeks stored in the command queue 162. If uncorrected pending seeks remain, the flow of the routine 192 returns to step 194 where a next pending seek command is evaluated. Steps 194 through 202 are thus repeated until all pending access commands stored in the command queue 162 have been evaluated.

The routine 192 next passes to step 206 where the control processor 142 sorts pending access commands using the average seek times derived from

corrected seek lengths. It will be understood that, while presently preferred sorting methodologies have been disclosed above, additional sorting schemes may be cooperatively employed with the methods disclosed by the present invention. These additional schemes include, for example, weighting the priority given to pending commands based on the order in which these commands are received by the command queue 162.

Once the sorting operation is concluded, a priority pending access command ("priority seek") is selected at step 208. At step 210, the priority access command is executed using the servo control circuit 138. Finally, at step 212, the executed access command is removed from the command queue 162. The ACCESS COMMAND SCHEDULING routine 192 is repeatedly applied to all pending access commands stored in the command queue 162.

In view of the foregoing, it will now be understood that the present invention is directed to an apparatus and method for transferring data between a disc drive and a host computer. In accordance with preferred embodiments, a disc drive (100) includes a rotatable disc (108) with a recording surface on which a plurality of concentric data tracks (133) are defined, each data track having a plurality of data sectors (134). A plurality of heads (118) are used to store data to and retrieve data from the data sectors. A servo circuit (138) performs seeks to move the head to positions adjacent selected tracks, each seek having an associated seek length distance with an average seek time. A control processor (140) controls the transfer of data between the disc and a host computer in response to an access command from the host computer.

The control processor calculates an estimated seek length as the radial distance between the an initial track and a destination track (step 194, FIG. 10). A positional offset value between each of the plurality of heads is measured and applied to the estimated seek length to calculate a corrected seek length (steps 198, 200). A corrected seek time is calculated from a seek profile table in relation to corrected seek length (step 202). The corrected seek time is used by the control processor to schedule the access commands stored in the command queue (step 206).

For purposes of the appended claims, the use of the term "over" will be understood consistent with the foregoing discussion to describe the relative placement of the associated head in a reading/writing relationship with the associated track, irrespective of the physical orientation of the track and head.

It will be clear that the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those inherent therein. While presently preferred embodiments have been described for purposes of this disclosure, numerous changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.

What is claimed is:

1. In a disc drive having a plurality of recording surfaces on which a plurality of concentric data tracks are respectively defined so that the tracks on the recording surfaces at each given radius make up a cylinder, a corresponding plurality of heads adjacent the respective recording surfaces, a servo circuit which selectively performs seeks to move the heads from an initial track to a destination track, and a control processor which schedules a plurality of pending access commands stored in a command queue, a method for optimizing the transfer of data between the recording surfaces and a host computer, comprising steps of:

(a) determining a radial positional offset between a presently active head and a different, target head with respect to the corresponding recording surfaces;

(b) identifying an estimated seek distance comprising a radial distance between an initial track over which the presently selected head is disposed and a destination cylinder having a destination track to which the target head is to be moved;

(c) identifying a corrected seek distance in relation to the positional offset;

(d) obtaining a corrected seek time from a seek profile table in relation to the corrected seek distance; and

(e) using the corrected seek time to schedule an access command associated with the destination track.

2. The method of claim 1, in which the determining step (a) further comprises a step of storing the measured positional offset values in a head offset table in memory accessible by the control processor.

3. The method of claim 1, in which the identifying step (c) further comprises a step of rounding the corrected seek distance to the nearest whole number of tracks.

4. The method of claim 1, further comprising a step of:

(f) executing a seek to place the target head over the destination track.

5. The method of claim 4, in which the executing step (f) comprises steps of:

(f1) applying current to an actuator motor to move the presently active head to a final cylinder different from the destination cylinder while using the presently active head to transduce servo data from the associated recording surface, wherein a radial distance between the final cylinder and the destination cylinder is nominally equal to the radial positional offset between the presently selected head and the target head; and

(f2) performing a head switching operation to switch to the target head so that the target head transduces servo data from the associated recording surface, wherein at the conclusion of the head switching operation the target head is nominally over the destination track.

6. The method of claim 4, in which the executing step (f) comprises steps of:

(f1) performing a head switching operation to switch to the target head; and

(f2) applying current to an actuator motor to move the target head to the destination cylinder while using the target head to transduce servo data from the associated recording surface.

7. A disc drive, comprising:

a plurality of recording surfaces on which a plurality of concentric data tracks are respectively defined so that the tracks on the recording surfaces at each given radius make up a cylinder;

a corresponding plurality of heads which store data to and retrieve data from the data tracks on the associated recording surfaces;

a servo circuit which selectively performs seeks to move the heads from an initial track to a destination track;

a memory which stores a plurality of pending access commands received from a host computer; and

a control processor which controls the transfer of data between the recording surfaces and the host computer in response to each access command, in which the control processor schedules the execution of the pending access commands in relation to a corrected seek time for each pending access command determined in relation to an estimated seek length as a radial distance between an initial cylinder over which a presently active head is located and a destination cylinder having a destination track corresponding to the associated access command, a radial positional offset value between the presently active head and a different, target head associated with the recording surface having the destination track, and a table of estimated seek times by seek length.

8. The disc drive of claim 7, in which the control processor stores the radial positional offset values in a head offset table in a memory accessible by the control processor.

9. The disc drive of claim 7, in which the servo circuit performs a selected one of the pending access commands to place the associated target head over the associated destination track by applying current to an actuator motor to move the presently active head to a final cylinder different from the destination

cylinder while using the presently active head to transduce servo data from the associated recording surface, wherein a radial distance between the final cylinder and the destination cylinder is nominally equal to the radial positional offset value between the presently selected head and the associated target head, and then performing a head switching operation to switch to the associated target head so that the associated target head transduces servo data from the associated recording surface, wherein at the conclusion of the head switching operation the associated target head is nominally over the destination track.

10. The disc drive of claim 7, in which the servo circuit performs a selected one of the pending access commands to place the associated target head over the associated destination track by performing a head switching operation to switch to the associated target head, and then applying current to an actuator motor to move the associated target head to the destination cylinder while using the associated target head to transduce servo data from the associated recording surface.

11. The disc drive of claim 1, in which the control processor rounds the corrected seek distance to the nearest whole number of tracks, and then identifies the corrected seek time from the table of estimated seek times by seek length using the rounded, corrected seek distance.

12. A disc drive, comprising:

a plurality of heads adjacent a corresponding plurality of recording surfaces on which a plurality of concentric data tracks are respectively defined so that the tracks on the recording surfaces at each given radius make up a cylinder; and

means for scheduling a plurality of pending access commands from a host computer to access a corresponding plurality of destination tracks on different recording surfaces each having an associated target head different from a presently active head, by determining a corrected seek time for each of the pending access commands which accounts for radial positional offset between the presently active head and the associated target head.

13. The disc drive of claim 12, wherein the means for scheduling comprises a control processor which schedules the execution of the pending access commands in relation to the corrected seek time for each pending access command determined in relation to an estimated seek length as a radial distance between an initial cylinder over which the presently active head is located and a destination cylinder having a destination track corresponding to the associated access command, a radial positional offset value between the presently active head and the associated target head, and a table of estimated seek times by seek length.

14. The disc drive of claim 12, wherein the means for scheduling performs steps of:

(a) determining a radial positional offset value between the presently active head and the associated target head with respect to the corresponding recording surfaces;

(b) identifying an estimated seek distance comprising a radial distance between an initial track over which the presently selected head is disposed and a destination cylinder having a destination track to which the associated target head is to be moved;

(c) identifying a corrected seek distance in relation to the positional offset;

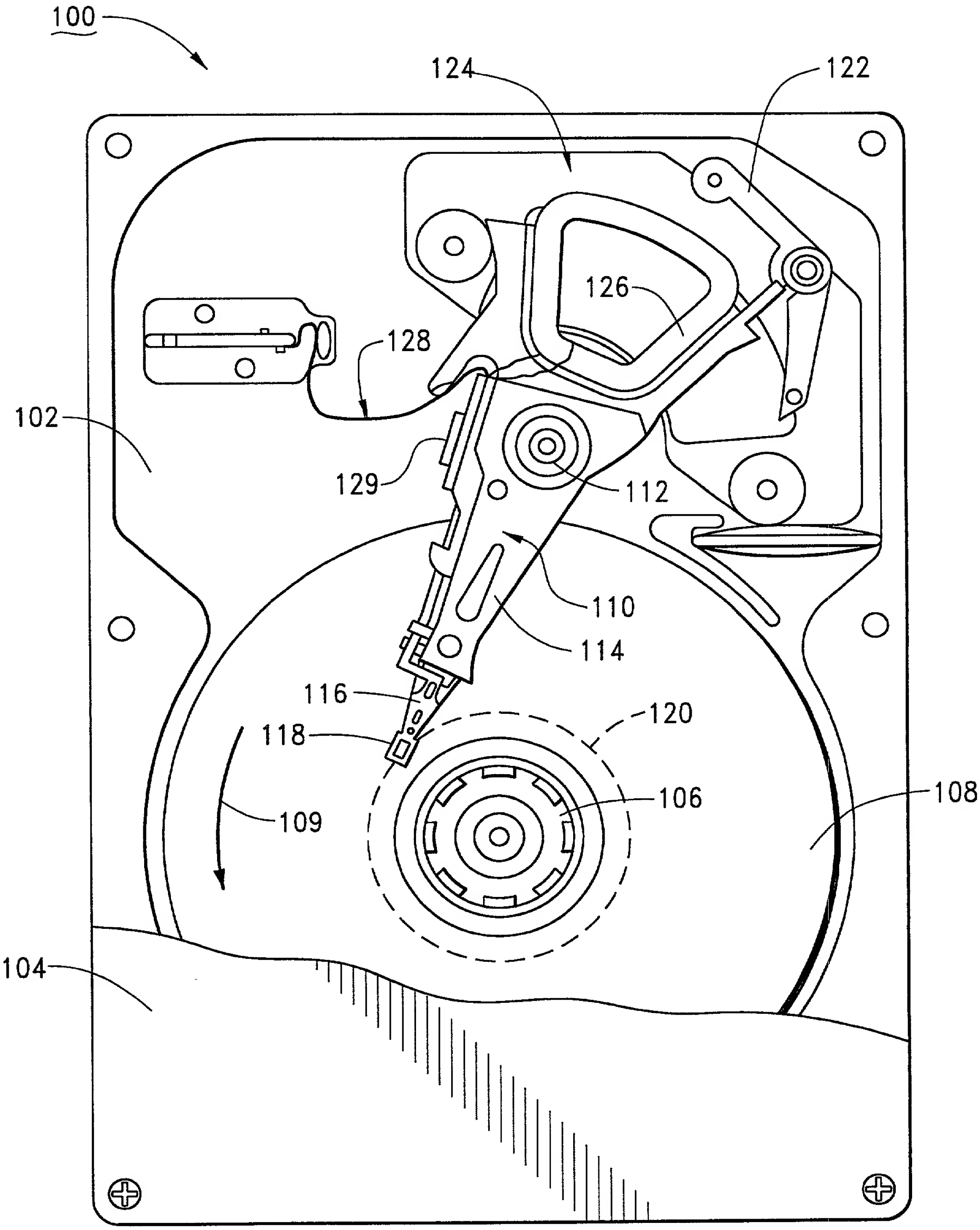
(d) obtaining a corrected seek time from a seek profile table in relation to the corrected seek distance; and

(e) using the corrected seek time to schedule the access command associated with the destination track.

IMPROVING PERFORMANCE IN A DISC DRIVE USING HEAD-TO-HEAD OFFSETS IN ACCESS COMMAND SCHEDULING

Abstract of the Disclosure

Apparatus and method for improving disc drive performance by compensating for head-to-head offsets when scheduling a plurality of pending access commands. A disc drive includes a plurality of recording surfaces on which a plurality of concentric data tracks are defined. A servo circuit performs seeks to move a plurality of heads from an initial track to a destination track. A positional offset between each of the plurality of heads is measured and applied to an estimated seek length to calculate a corrected seek length. A corrected seek time is calculated from a seek profile table in relation to corrected seek length. The corrected seek time is used by a control processor to schedule the access commands stored in the memory.


100
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122
126
128
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129
112
110
114
116
120
118
106
109
108
104

FIG. 1

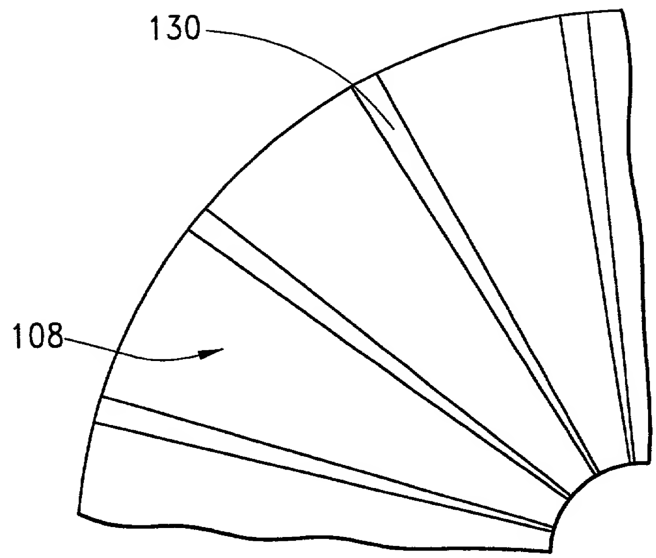


FIG. 2

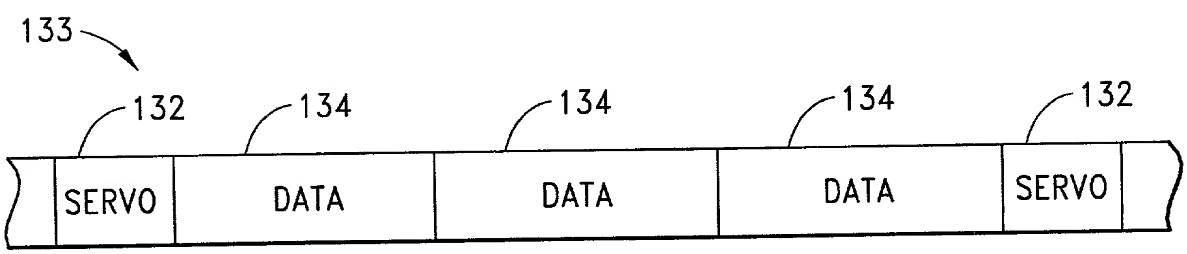


FIG. 3

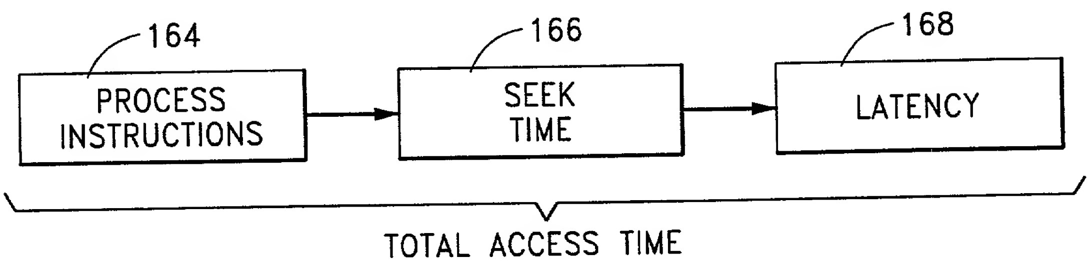
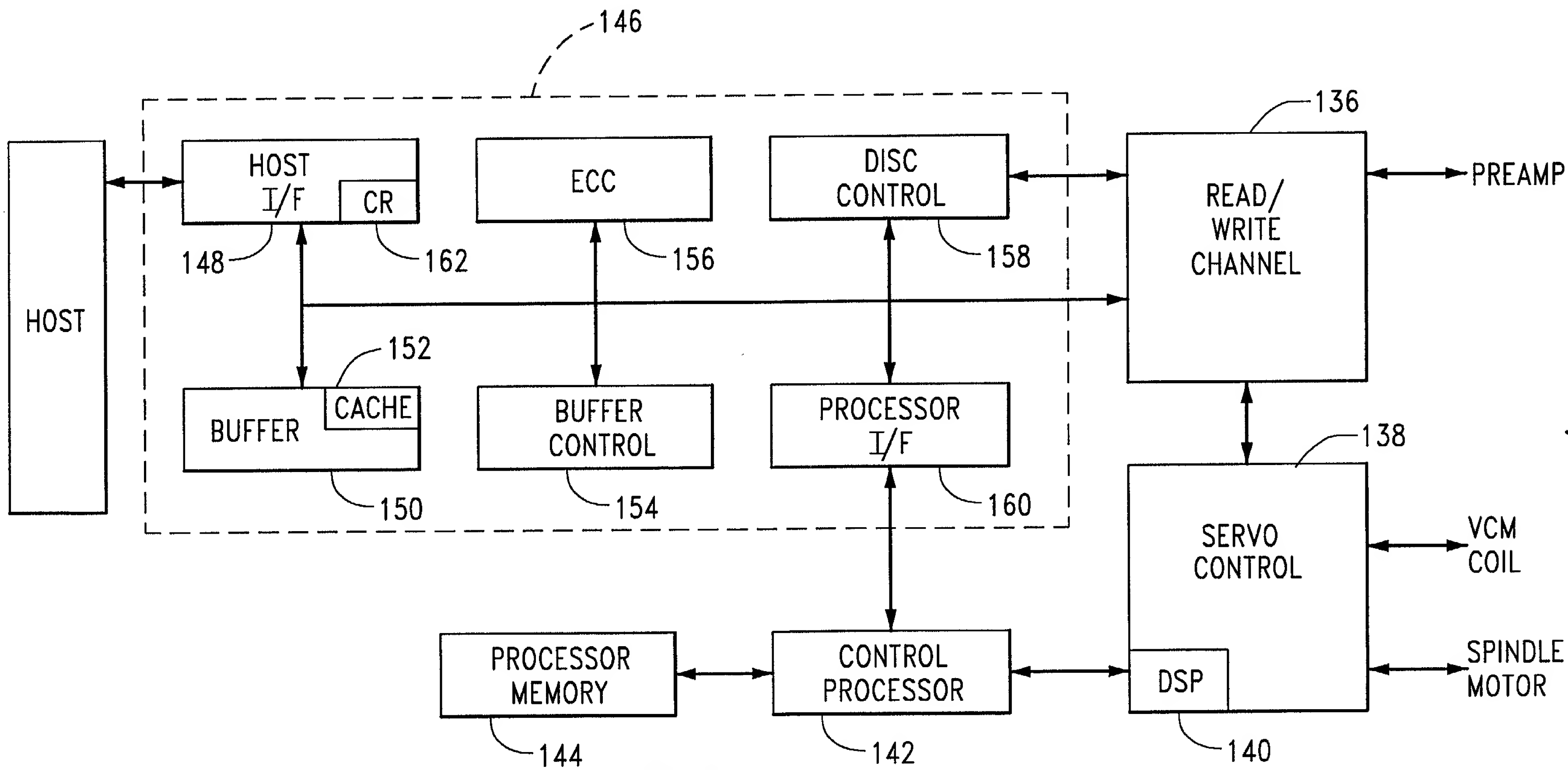


FIG. 5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HOST
HOST I/F
CR
148
162
ECC
156
DISC CONTROL
158
136
READ/ WRITE CHANNEL
PREAMP
BUFFER
CACHE
152
150
BUFFER CONTROL
154
PROCESSOR I/F
160
138
SERVO CONTROL
VCM COIL
SPINDLE MOTOR
DSP
140
PROCESSOR MEMORY
144
CONTROL PROCESSOR
142

FIG. 4

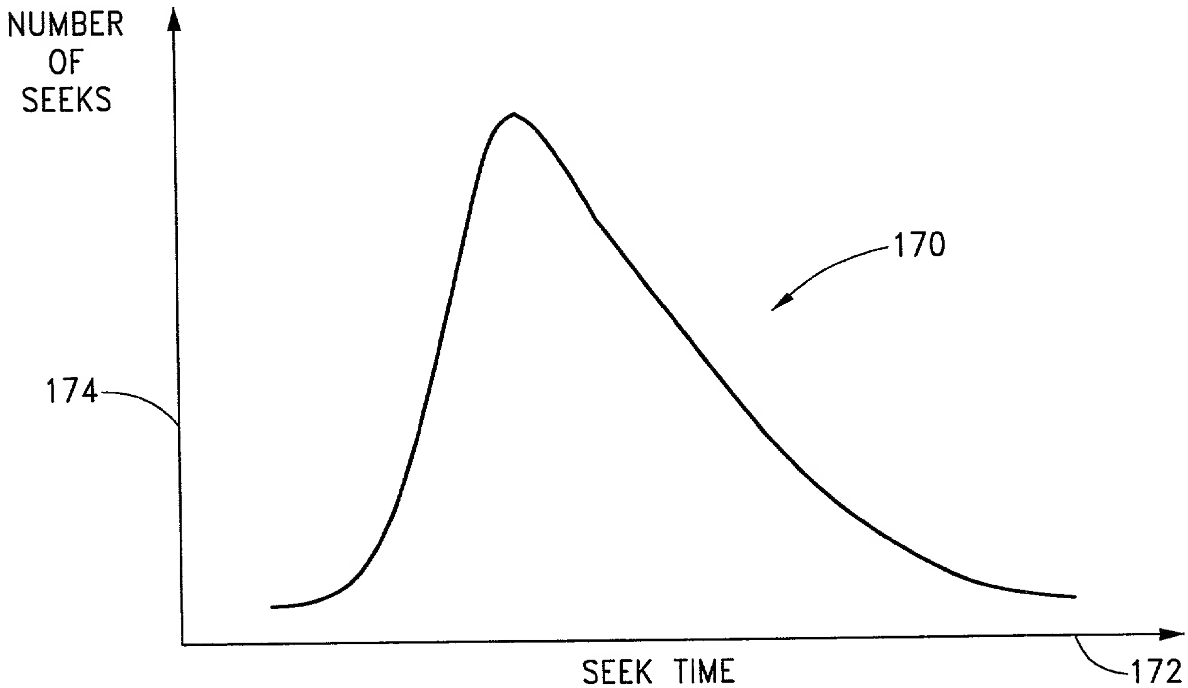

NUMBER
OF
SEEKS
170
174
SEEK TIME
172

FIG. 6

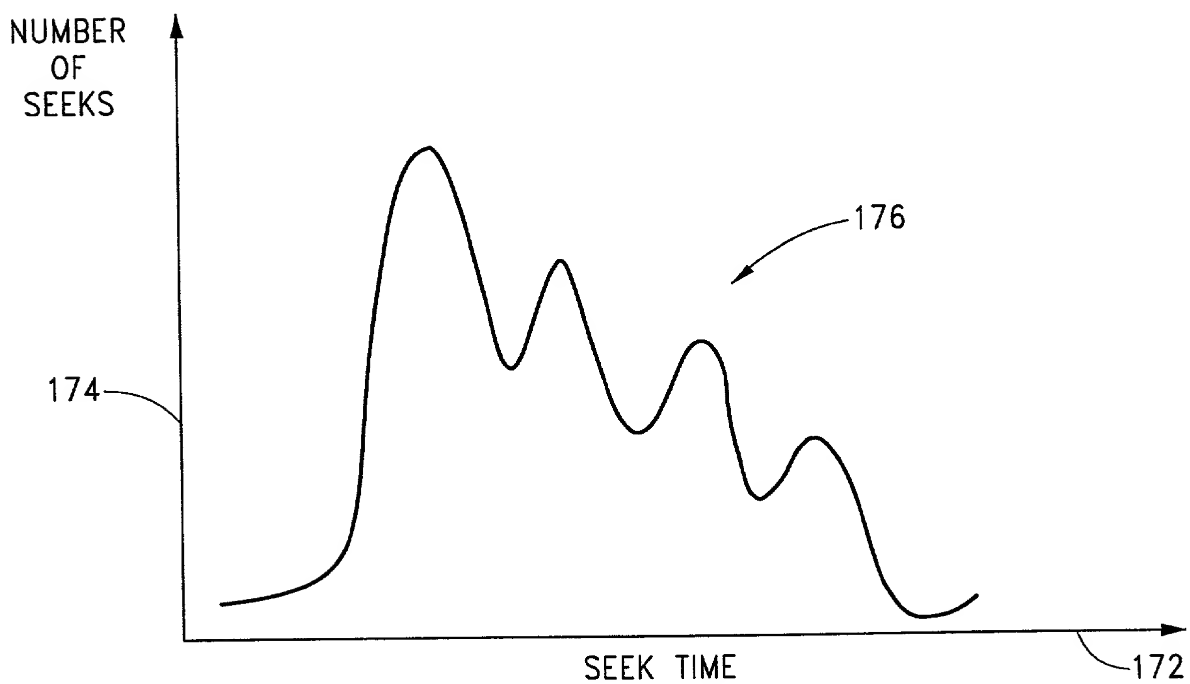
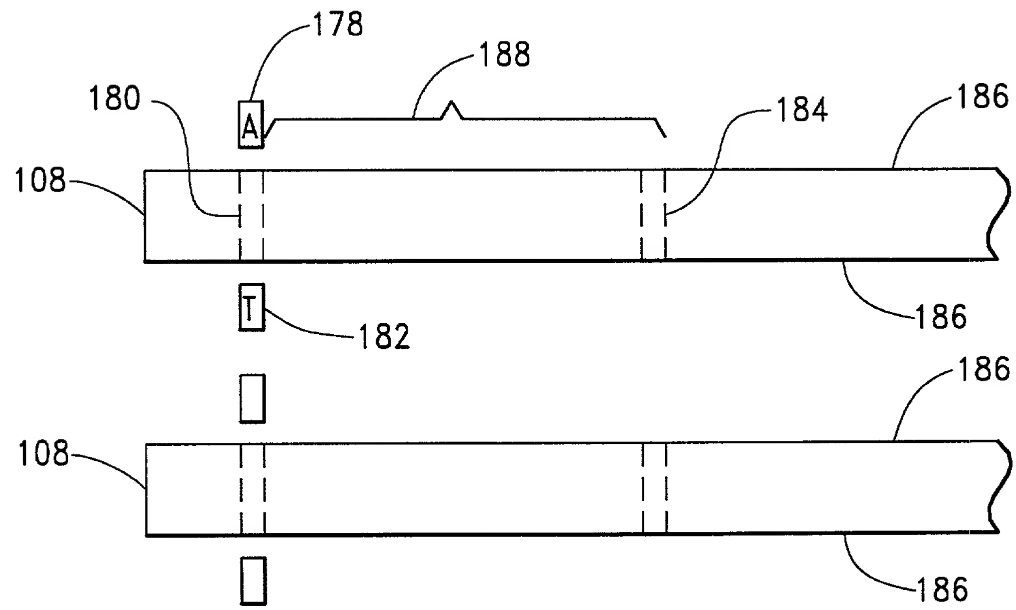

NUMBER
OF
SEEKS
176
174
SEEK TIME
172

FIG. 7


178
188
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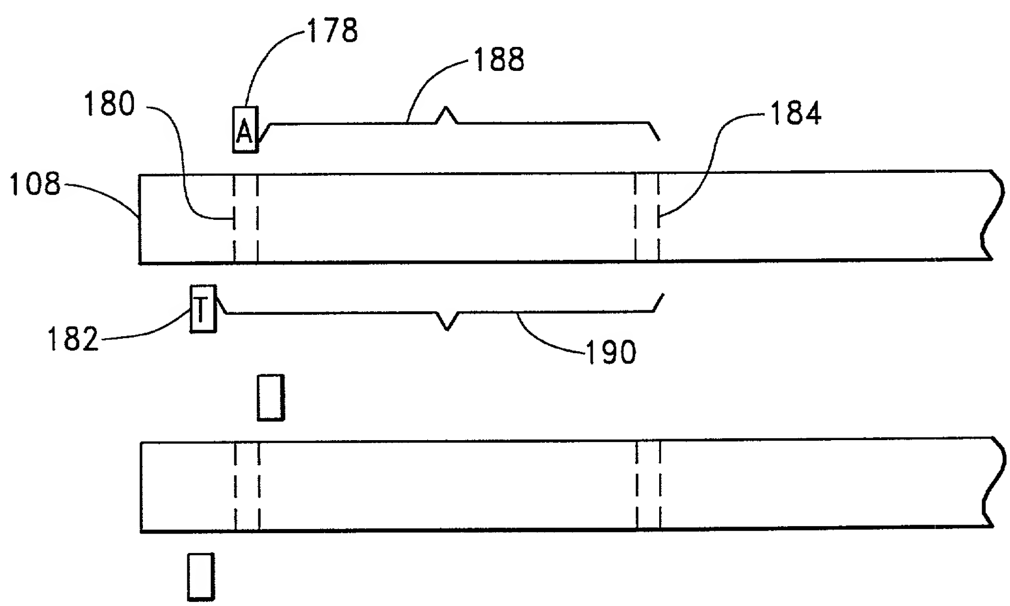
A
184
186
108
T
182
186
186
108
186

FIG-8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184
108
182
T
190

FIG-9

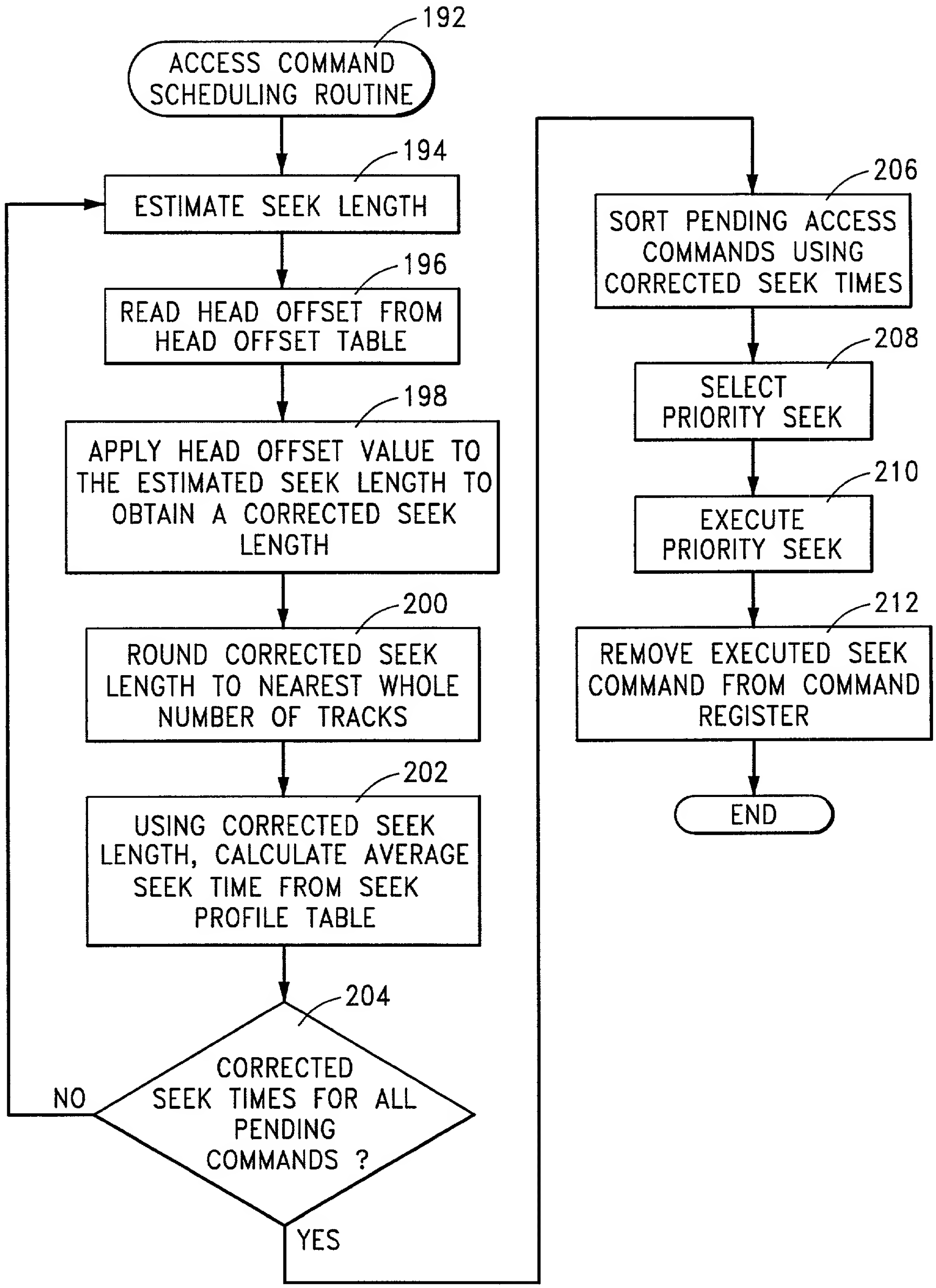
ACCESS COMMAND SCHEDULING ROUTINE
192
ESTIMATE SEEK LENGTH
194
READ HEAD OFFSET FROM HEAD OFFSET TABLE
196
APPLY HEAD OFFSET VALUE TO THE ESTIMATED SEEK LENGTH TO OBTAIN A CORRECTED SEEK LENGTH
198
ROUND CORRECTED SEEK LENGTH TO NEAREST WHOLE NUMBER OF TRACKS
200
USING CORRECTED SEEK LENGTH, CALCULATE AVERAGE SEEK TIME FROM SEEK PROFILE TABLE
202
CORRECTED SEEK TIMES FOR ALL PENDING COMMANDS ?
204
NO
YES
SORT PENDING ACCESS COMMANDS USING CORRECTED SEEK TIMES
206
SELECT PRIORITY SEEK
208
EXECUTE PRIORITY SEEK
210
REMOVE EXECUTED SEEK COMMAND FROM COMMAND REGISTER
212
END

FIG. 10

EXPRESS MAIL RECEIPT NO. EK281428778US *PATENT*
DEPOSITED ON OCTOBER 24, 2000 **Dkt. 23060**

DECLARATION FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **IMPROVING PERFORMANCE IN A DISC DRIVE USING HEAD-TO-HEAD OFFSETS IN ACCESS COMMAND SCHEDULING**, the specification of which is attached hereto unless the following box is checked:

___ was filed on_________ as United States Application Number or PCT International Application Number________ and was amended on ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Claimed

__________________ __________________ __________________ __ Yes __ No
(Number) (Country) (Day/Month/Year Filed)

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

60/183,102 **February 17, 2000**
(Application Number) (Filing Date)

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this

application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

(Application Number)	(Filing Date)	(Status - patented,pending, abandoned)
(Application Number)	(Filing Date)	(Status - patented,pending, abandoned)

Address all telephone calls to **Bill D. McCarthy** at telephone number **(405) 235-7700** or facsimile number **(405) 239-6651**.

Address all Correspondence to:

Bill D. McCarthy
CROWE & DUNLEVY
1800 Mid-America Tower
20 N. Broadway
Oklahoma City, Oklahoma 73102-8273.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor (given name, family name)

Jack A. Mobley

Inventor's signature Jack A. Mobley Date: 10/20/2000

Residence **Oklahoma City, Oklahoma 73162**

Citizenship **United States of America**

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Jason D. Gregg

Inventor's signature ______________ Date: 10/20/2000

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Citizenship **United States of America**

Post Office Address **314 N.W. 20th Street, Oklahoma City, Oklahoma 73103**

Full name of third joint inventor, if any (given name, family name)

Kenny T. Coker

Inventor's signature Kenny T. Coker Date: 10/20/2000

Residence **Mustang, Oklahoma 73064**

Citizenship **United States of America**

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Full name of fourth joint inventor, if any (given name, family name)

Leonard D. Doss

Inventor's signature Leonard D. Doss Date: 10/20/2000

Residence **Oklahoma City, Oklahoma 73119**

Citizenship **United States of America**

Post Office Address **2713 Texoma Drive, Oklahoma City, Oklahoma 73119**

EXPRESS MAIL RECEIPT #: EK281428778US
DEPOSITED ON OCTOBER 24, 2000

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor:	**Jack A. Mobley, et al.**
Serial No.:	**Not Yet Assigned**
Filed:	**October 24, 2000**
Docket:	**23060**

JC914 U.S. PTO
09/696269
10/23/00

POWER OF ATTORNEY BY ASSIGNEE OF ENTIRE INTEREST (REVOCATION OF PRIOR POWERS)

As assignee of record of the entire interest of the above identified application,

REVOCATION OF PRIOR POWERS OF ATTORNEY

all powers of attorney previously given are hereby revoked and

NEW POWER OF ATTORNEY

the following practitioners/patent agent are hereby appointed to prosecute and transact all business in the Patent and Trademark Office connected therewith

Shawn B. Dempster, Registration No. 34,321	Edward P. Heller, III, Registration No. 29,075
Raghunath S. Minisandram, Registration No. 38,683	Jonathan E. Olson, Registration No. 41,231
Leland D. Schultz, Registration No. 30,322	Cecilia A. (Peggy) Walsh, Registration No. 45,659
Derek J. Berger, Registration No. 45,401	

And members of the firm of Crowe & Dunlevy

Bill D. McCarthy, Registration No. 26,772
Randall K. McCarthy, Registration No. 39,297
Daniel P. Dooley, Registration No. 46,369

CHANGE OF ATTORNEY'S/AGENT'S ADDRESS IN APPLICATION

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1800 Mid-America Tower
20 North Broadway
Oklahoma City, OK 73102-8273
Telephone No.: (405) 235-7700
Fax No.: (405) 239-6651

STATEMENT UNDER 37 CFR 3.73 (b)

Seagate Technology LLC states that it is the Assignee of Entire Interest in the patent application/patent identified above by virtue of an Assignment from the inventor(s) of the patent application/patent identified above. A copy of the Assignment is attached and/or was recorded in the Patent and Trademark Office at
Reel , Frame . The undersigned (whose title is supplied below) is empowered to sign this statement on behalf of the Assignee.

Respectfully submitted,

SEAGATE TECHNOLOGY LLC
(Assignee of Entire Interest)

22 October 2000
Date

Shawn B. Dempster, Reg. No. 34,321
Senior Director of Intellectual Property, Product and Technology Development
SEAGATE TECHNOLOGY LLC
Intellectual Property Dept. – SHK2LG
1280 Disc Drive
Shakopee, MN 55379-1863
(952) 402-2517 (telephone)
(952) 402-2657 (facsimile)

09509207.113002

EXPRESS MAIL RECEIPT NO.EK281428778US
(Joint) SEAGATE

Docket No. **23060**
SEA **9496**

ASSIGNMENT

WHEREAS, we, **Jack A. Mobley, Jason D. Gregg, Kenny T. Coker and Leonard D. Doss,** are the joint inventors of an invention in **IMPROVING PERFORMANCE IN A DISC DRIVE USING HEAD-TO-HEAD OFFSETS IN ACCESS COMMAND SCHEDULING**, for which we have executed an application for United States Letters Patent; and

WHEREAS, Seagate Technology LLC, a limited liability company organized and existing under and by virtue of the laws of the State of Delaware and having a place of business at Scotts Valley, California, is desirous of acquiring the entire right, title and interest in and to said application and said invention, as well as any and all applications for Letters Patents and Inventor's Certificates which may be filed on said invention in any country or countries, as well as any and all Letters Patents and Inventor's Certificates which may be granted on any such application.

NOW, THEREFORE, for valuable consideration, the receipt and adequacy of which is hereby acknowledged, we have sold, assigned, transferred and set over, and by these presents do hereby sell, assign, transfer and set over unto Seagate Technology LLC, its successors and assigns, our entire right, title and interest in, to and under said invention and said application, and any and all Letters Patents which may be granted for said invention and/or on said application, including all extensions, continuations, divisions and reissues thereof, and our right of priority under the International Convention for the Protection of Industrial Property, the Inter-American Convention relating to Inventions, Patents, Designs and Industrial Models, and any other convention, treaty or reciprocal agreement to which the United States is a party concerning priority in inventions, patents, designs, inventor's certificates, industrial property or industrial models, and any and all applications for Letters Patent or Inventor's Certificate which has heretofore or may hereafter be filed on said invention in any country or countries, as well as any and all Letters Patents and Inventor's Certificates which may be granted on any such application, including all extensions, continuations, divisions, reissues and renewals thereof; the same to be held and enjoyed by Seagate Technology LLC for its own use and behoof and for the use and behoof of its successors and assigns as fully and entirely as the same would have been held and enjoyed by us had this assignment not been made;

AND we covenant that we have not and will not execute any instrument or take any action contrary to this assignment, nor encumber the title of Seagate Technology LLC, in, to and under said invention, applications, Letters Patents and Inventor's Certificates, and that we have the right to execute this instrument;

AND we, and each of us, hereby covenant and agree to keep Seagate Technology LLC advised of our current residence addresses, and we, and each of us, or our executors, administrators, representatives or assigns, will execute all papers, make all rightful oaths, and do all acts deemed by Seagate Technology LLC, its successors and assigns, necessary or desirable in any proceeding concerning any of said applications or Letters Patents or Inventor's Certificates, including, but not limited to, proceedings for the procurement or enforcement of Letters Patents for said invention, or for the reissue, renewal or extension thereof, at the expense of Seagate Technology LLC but without charge to Seagate Technology LLC, its successors and assigns.

We hereby request the Commissioner of Patents of the United States, and any official of any country foreign to the United States whose duty is to issue Letters Patents or Inventor's Certificates on applications as aforesaid, to issue Letters Patents or Inventor's Certificates to Seagate Technology LLC or its designee in accordance with this instrument.

ASSIGNORS hereby covenant that no assignment, sale, agreement or encumbrance has been or will be made or entered into which would conflict with this Assignment and sale.

Date: 10/20/2000 — Jack A. Mobley
Jack A. Mobley, ASSIGNOR

Date: 10/20/2000 — [signature]
Jason D. Gregg, ASSIGNOR

Date: 10/20/2000 — Kenny T. Coker
Kenny T. Coker, ASSIGNOR

Date: 10/20/2000 — Leonard D. Doss
Leonard D. Doss, ASSIGNOR

STATE OF **OKLAHOMA**)
) ss.
COUNTY OF **CANADIAN**)

This instrument was acknowledged before me, a Notary Public, on this 20 day of October (Month), 2000 by Jack A. Mobley.

Nancy Marshall
Notary Public

My Commission Expires:
September 6, 2004

STATE OF **OKLAHOMA**)
) ss.
COUNTY OF **CANADIAN**)

This instrument was acknowledged before me, a Notary Public, on this 20 day of October, 2000 by Jason D. Gregg.
(Month)

Nancy Marshall
Notary Public

My Commission Expires:
September 6, 2004

STATE OF **OKLAHOMA**)
) ss.
COUNTY OF **CANADIAN**)

This instrument was acknowledged before me, a Notary Public, on this 20 day of October, 2000 by Kenny T. Coker.
(Month)

Nancy Marshall
Notary Public

My Commission Expires:
September 6, 2004

STATE OF **OKLAHOMA**)
) ss.
COUNTY OF **CANADIAN**)

This instrument was acknowledged before me, a Notary Public, on this 20 day of October 2000 by Leonard D. Doss.
(Month)

Nancy Marshall
Notary Public

My Commission Expires:
September 6, 2004